CONCRETE BRIDGE DETAILS

PORTLAND CEMENT ASSOCIATION

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TO OUR FRIENDS IN ENGINEERING

A CLEAR distinction between *good* and *bad* is seldom justifiable in the study of technical subjects. In bridge building, for example, bad practice does not exist—in a sense—since it has to a great extent been discredited and discarded. It seems equally true that good practice—in the sense of perfection—has not yet been achieved. Bridge building is still in an intermediate stage on the road of progress. It is expedient at times to look back and survey past stages for the purpose of outlining the future course. This is the viewpoint taken in the preparation of this booklet.

No published records were known to deal with practice in bridge construction as it is treated here. Hence, it has been deemed wise to let the discussion go beyond the known present practice. Care has been taken to avoid presenting ideas as new, for what may appear new might possibly have been used previously. The plan has been not to pass judgment but to present a discussion based upon field observations. It has been the purpose to offer constructive suggestions hoping to accelerate progress.

The figures and marginal notations are arranged to give an outline of the topics treated and will therefore give a good idea of the scope of the studies. The text is grouped around the corresponding figures and may be referred to as the need arises for studying individual subjects.

Portland Cement Association

CONCRETE BRIDGES

A discussion of structural details

INTRODUCTION

CONCRETE occupies a prominent position as a bridge building material. Beauty and economy, low maintenance cost and long life are among its advantages. By modern methods of proportioning, concrete is being made with a density to withstand severe outdoor exposures, and predetermined strengths can be obtained consistently. Recognition of the improvements in concrete making is gradually being given by increasing the working stresses. Corresponding developments have taken place in the application of principles of continuity to bridge design.

Successful designs in concrete, as in other building materials, are frequently marred by isolated imperfection of detail. In order to ascertain the structural shortcomings and learn how to avoid them, a survey of concrete bridges was undertaken late in 1933. This survey, during which attention was focused on the details needing improvement, was augmented by information obtained through the cooperation of several state highway bridge officials.

Practically no signs of distress were observed in the structural elements—slab and girders—which form the usual deck girder construction. Cracks were seen in only very few instances, and these were insignificant.

While deck girders were seen to be virtually without defects, some abutments revealed signs of structural flaws. It became evident as the survey progressed that most of the defects were of structural nature. The types of cracks observed were evidence of tensile strains that could either be taken care of or be eliminated. Where this was not done, secondary effects were sometimes in evidence, such as leakage accompanied by local damage.

The observations indicated that abutments in general do not actually behave according to assumptions. The conventional analysis of the common type of abutment is at best only an approximation and frequently is considerably in error.

Some progress has been made by simply strengthening the abut-

ment without changing the conventional type of layout. Remedies of this kind are of necessity empirical. It is preferable in some cases to develop new improved types that are subject to a more rational analysis in order to satisfy the modern demands for permanence and economy. In the development of new types—and in the general improvement of structural details for bridges—lies a possibility of greater progress.

ABUTMENTS

General Considerations

Bridge abutments perform a double function; they carry the load from the superstructure down to the foundation and also act as retaining walls confining the embankment fill. The problem of developing suitable details for this two-fold function is complicated by the fact that most elements in abutment design are not susceptible to a rational analysis of stresses. This has prompted bridge designers to experiment continually with new abutment types. Considerable progress has been made of late and meritorious designs have been worked out.

The sections that follow present a discussion of what is believed to be the most advanced practice in abutment construction in its present stage. The manifestations of strain within the abutment itself are treated in the sections on *Footings*, *Breastwalls* and *Wingwalls*, which include also studies of construction details that have been found to give excellent results, together with suggested details that may cause further advance in the construction of abutments. The phenomena that are contributing or original causes of the strains have been taken up principally in the sections on *Abutment Movements* and *Creep in Skew Bridges*.

ABUTMENT FOOTINGS

Movements of Footings

It is not safe to assume that footings are immovable in cases where they are built on foundations other than rock or well cemented strata. Footings may move horizontally as well as settle vertically and the movements may be non-uniform. Horizontal movements may take place as the result of pressure of backfill or irregular foundation conditions.

FIG. 1

It is often possible to excavate the trench for the footing without bracing the soil. In this case it is customary to fill the entire width of the footing trench with concrete. Similarly, the entire

width of the trench may be concreted in one operation if the construction of a cofferdam is required, provided the sheet piling is to be left in place. In other instances, the sheet piling may be withdrawn while a concrete backfill as shown in Fig. 1* is being placed. A construction in which the footing concrete is tightly wedged between two vertical planes of virgin soil appears to have considerable merit.

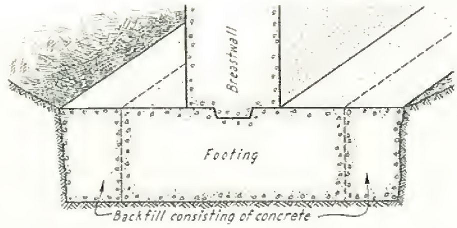


FIG. 1 Horizontal movement of the footing is checked when the concrete fills the full width of the footing trench.

FIG. 2

Hinged Footings for Rigid Frames

In connection with rigid or continuous frames, it is sometimes expedient to build the construction joint at the top of the footing so that no moment can be transmitted across the joint. The use of joints of the hinged types shown in Fig. 2 has the advantage of making the foundation pressure approximately uniform and may therefore simplify the design of the footing as well as the analysis of the frame. Similar joints with a cylindrical recess in the footing designed for hinge action have also been used in rigid frame bridges. The centerline of the cylinder must be above the top of the footing in order to permit unrestricted rocking in the joint.

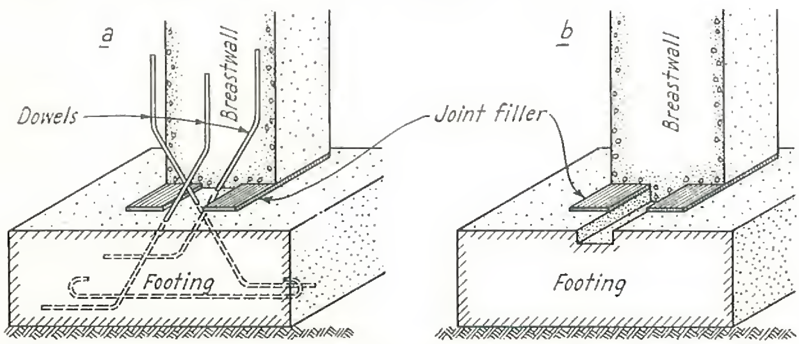


FIG. 2 Construction joints with hinge action at top of footings. Type *a* has a better hinge action, but type *b* has a better shear connection.

FIG. 3

Rectangular footings tend to settle most near the center. The tendency is even more pronounced in abutment footings that are

*Note that this as well as the following sketches are not necessarily drawn to scale.

Reinforcing Footing to Prevent Cracks

built continuously under both breastwalls and wingwalls, because the load intensity usually is greater under the breastwall. Cracks of the type marked *d*, which are comparatively rare, are caused by sagging. The development of crack *d* (Fig. 3) should be considered, and it is advisable to use a comparatively large amount of reinforcement placed continuously at the bottom of the footing, as indicated by bars *d* in Fig. 4.

BREASTWALLS

Breastwall Types

Three types of breastwall are commonly used: namely, the gravity wall of plain concrete, the cantilever wall of reinforced concrete, and the type of wall that acts as a vertical beam supported

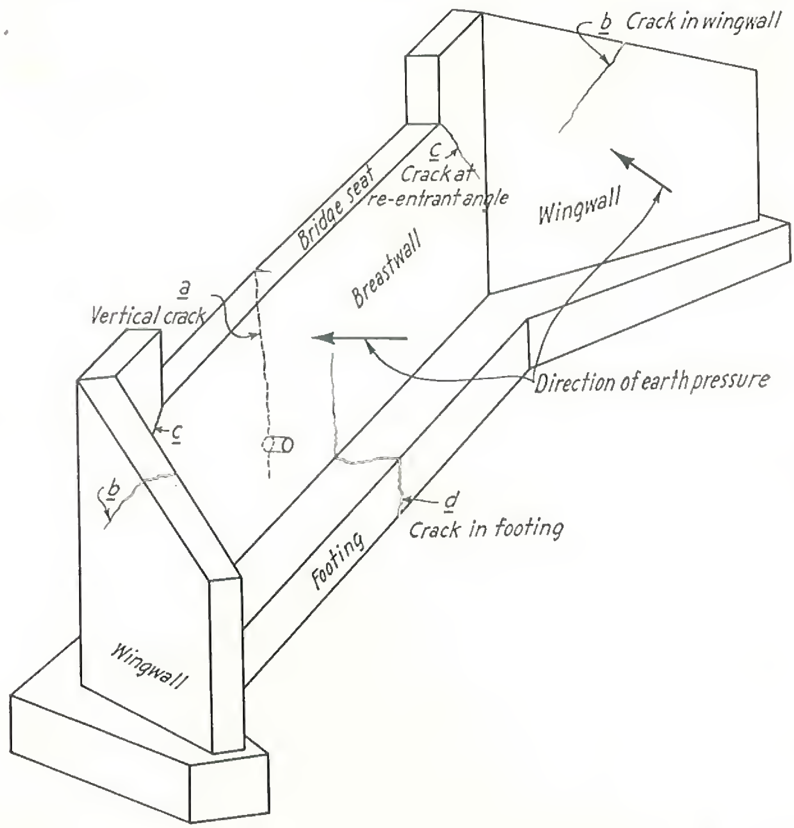


FIG. 3 Typical cracks that may develop in the common abutment type when the conventional analytical methods take little or no account of the actual behavior of the abutment.

horizontally by the deck and by the foundation. There are also several modified types such as the semi-gravity and the buttressed retaining wall.

Causes of Tension in Breastwalls

The cantilever retaining wall, probably the type most commonly used for breastwalls, sometimes develops cracks similar to *a* in Fig. 3. Such cracks may be prevented as will be seen after a brief discussion of their contributing causes, among which are: (a) non-uniform shrinkage, (b) a discrepancy between design assumptions and actual behavior, and (c) the earth pressure on wingwalls. The relative effects of these phenomena are uncertain, but all of them act to create tension in the front face of the breastwall.

Shrinkage in abutment walls may be non-uniform because the front surface, being exposed, dries out in relation to the rear surface that is kept moist by the adjacent fill. This shrinkage tends to set up tensile stresses in the breastwall.

Design Discrepancies

In studying the discrepancy between design assumption and actual behavior, consider an abutment of the type shown diagrammatically in Fig. 3. The breastwall is assumed in the design to be a cantilever retaining wall and is reinforced accordingly; that is, the reinforcement is placed near the rear face. In reality, the wall acts

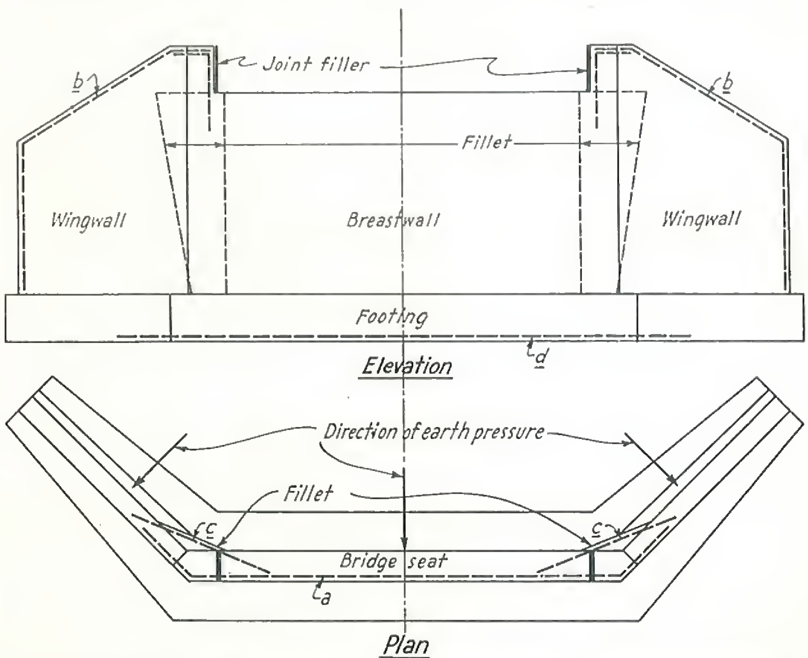


FIG. 4 Common abutment type, reinforced and strengthened. The ordinary abutment reinforcement is not shown.

partly as a simple vertical cantilever, and partly as a box retaining wall braced at the ends by the wingwalls acting as counterforts. Wall slabs of this type have tensile stresses in the front face midway between the counterforts and should be reinforced accordingly with horizontal bars near the front face. Unfortunately, all the reinforcement in ordinary breastwalls is placed near the rear face; but the horizontal bars would be more effective if placed near the front face.

The wingwalls in Fig. 3 are also designed and built as cantilever retaining walls but are cast monolithically with the breastwall, with two results: the whole abutment acts as a unit, and the earth pressure on flared and parallel wingwalls produces tension in the breastwall.

FIG. 4

Bars in Front Face

According to this discussion, an abutment of the type shown in Fig. 3 can be improved by adding horizontal bars near the front face. Bars *a* in Fig. 4 provide for both horizontal beam action and shrinkage, and are recommended for use with the regular reinforcement provided for cantilever action. In addition, it is sometimes advisable to place vertical bars near the front face. These bars will take the tensile stresses developed in case the breastwall acts as a vertical beam supported horizontally by the deck and by the foundation, a loading condition that will be discussed in the section on *Abutment Movements.*

Joint Action with Wingwalls

The joint action between breastwall and wingwalls is difficult to analyze, and the safe and economical amount of reinforcement can seldom be calculated. If the bar areas provided happen to be inadequate, small cracks may still develop. As a further precaution, vertical grooves should be used on the front face of breastwalls. The grooves are sometimes placed in combination with vertical construction joints, in which case the reinforcement should be continuous across the joint. The small crack will then be inconspicuous because it will follow the bottom of the groove, and membrane waterproofing applied at the joint on the rear face will prevent seepage. The best result is obtained when weep holes are placed at

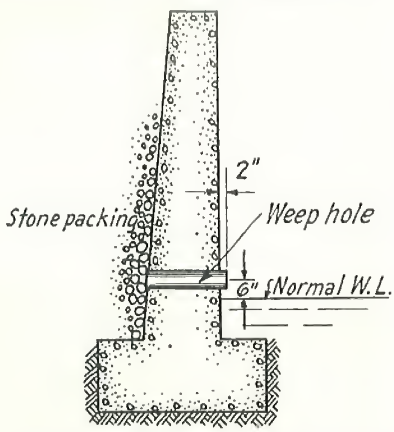


FIG. 5 Weep holes with proper stone packing are important in making abutments durable.

the vertical construction joints. At least one state highway department follows this practice with good results.

FIG. 5

Drainage of Backfill

All box-type abutments should have provision for drainage of the backfill. This involves drain pipes acting as weep holes placed in the walls as indicated in Fig. 5. The openings should be large, say 6 inches in diameter, especially where there is danger of clogging with dirt or ice.

The backfill should be selected with care since it greatly affects the safety and durability of abutments. The fitness of a backfill material is principally judged by its behavior when it absorbs and releases water. Silt and loam, for example, have objectionable characteristics and may, when wet, exert pressures considerably in excess of those for which the abutments were designed. Coarse materials are better suited for backfill behind abutments because they quickly release entrapped water and therefore exert a minimum pressure on the confining walls. Coarse material may be costly to use for the entire backfill. If so, it is often used in a layer only, about 12 inches thick, placed against the rear abutment surface.

WINGWALLS

The wingwalls are usually of the same type as the breastwall but differ from it in that they are topped by a simple coping without provision for support of any superstructures. They will be referred to as parallel, flared, curved, or straight wingwalls.

FIG. 6

Cracks that may develop in wingwalls and at the junction of wingwall and breastwall are designated as *b* and *c* in Fig. 6*a* and in

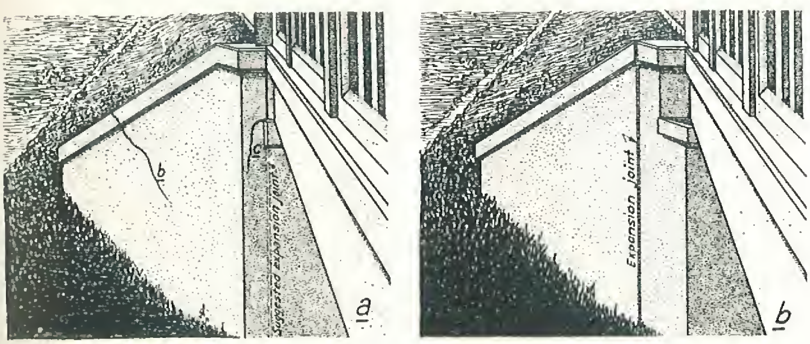


FIG. 6 Cracks *b* and *c* in abutment with monolithic wingwalls (type *a*) may be avoided if the wingwalls are separated from the breastwall by expansion joints. Two types of joint layout are indicated.

Fig. 3 (page 8). What is the cause of these cracks and how may they be prevented?

Stresses along Coping

An abutment of the type shown in Fig. 6*a* may behave partly as a box retaining wall in which the wingwalls act as counterforts. Tensile stresses are developed accordingly along the coping of the wingwall, but adequate reinforcement is seldom provided. The development of cracks of type *b* may therefore be a result of the discrepancy between assumption and reality in abutment action. Additional tensile strains are created since flared or parallel wingwalls have a tendency to pull away from the breastwall. Because this tendency is rarely considered in the design, cracks of type *c* may develop as sketched in Figs. 3 and 6*a*.

FIG. 7

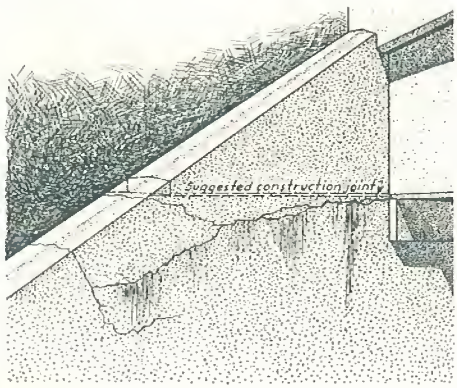


FIG. 7 The cracks in this type of abutment may be avoided by use of a construction joint as indicated.

Fig. 7 illustrates cracking that may occur in wingwalls built in direct extension of the breastwall. Such cracks are sometimes observed where the abutting surfaces in the vertical joint between the wingwall and the outer girder have not been kept apart with a soft filler. In such cases, relative movement of the abutment with respect to the deck—tilting of the abutment or lateral creep of the deck—may be harmful.

Two conclusions may be drawn from the observations made: (a) tensile stresses of considerable magnitude may be set up in the concrete by phenomena frequently originating outside the structure, and (b) no structural analysis is available by which the stresses may be determined.

Improved Wingwall Design

Accordingly, there appear to be only two methods whereby improvements may be made: (a) suitable reinforcement may be provided—by judgment or empirical rules—in the conventional type of abutments, or (b) improved abutment layouts may be adopted in which the critical strains are eliminated.

Using the first method, wingwall cracks of type *b* in Fig. 3 may be eliminated by adding sufficient reinforcement as indicated by bars marked *b* in Fig. 4.

Cracks like *c* at the end of the bridge seat shown in Fig. 3 can

also be avoided; the methods indicated in Fig. 4 have been used with good results for relatively shallow abutments with heights up to about 15 feet. The deck and wingwall are separated by a soft joint filler at least ¾ inch thick. The junction between wingwall and breastwall is strengthened by means of a concrete fillet which is reinforced with bars marked *c*. It is advisable to use several *c*-bars in the plane just below the bridge seat. The proportions of the filler and the amount of reinforcement must be based upon judgment. Such methods of reinforcing the conventional abutment often have been found effective.

Additional Reinforcing in Conventional Wingwalls

An example of an improved design adopted to eliminate critical strains is illustrated in Fig. 6*a*, in which the double dotted line indicates a vertical expansion joint. The tensile strains responsible for cracks are then eliminated and the wingwall acts as a simple retaining wall and not simultaneously as a counterfort. It is evident that a lateral pressure of the deck against the top of the wingwall will merely widen the space in the expansion joint, and critical tensile strains are eliminated where crack *c* might otherwise develop. A similar effect is obtained in the construction sketched in Fig. 6*b*.

Vertical Expansion Joints

FIG. 8

A type of vertical expansion joint recently used in abutments is illustrated in Fig. 8. It was found to eliminate cracks at the wingwall coping but not at the end of the bridge seat and was therefore abandoned. Cracks at both places may be eliminated with the joint position in Fig. 8, provided the bridge seat is constructed as sketched in Fig. 6*b*, or the joint may be moved to the position shown in Fig. 6*a*.

FIG. 9

Vertical expansion joints placed at the end of the bridge seats in most rigid frame bridges (see arrow, Fig. 9) have been successful. The separation of

FIG. 8 A vertical expansion joint separates wingwall from breastwall. This is a desirable feature provided the joint is placed at the end of the bridge seat as an extension of the joint shown there.

FIG. 9 In rigid frame bridges, wingwalls are generally separated from the breastwall by expansion joints. (See arrow.)

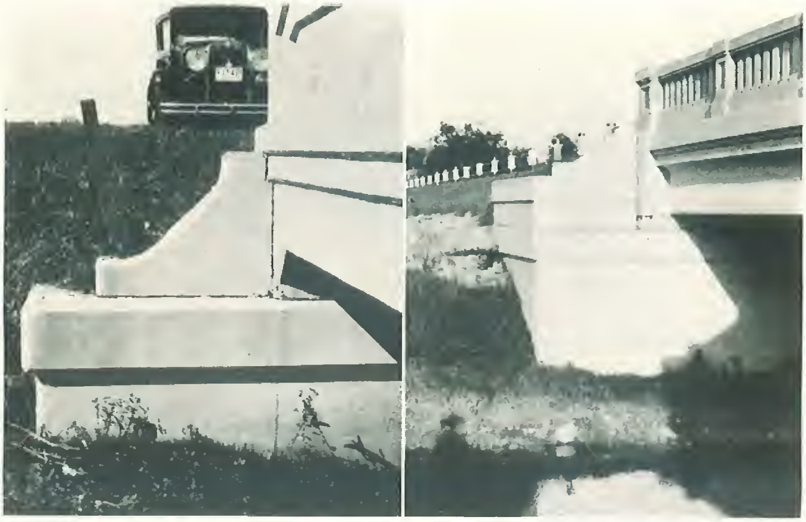
wingwall from breastwall is desirable because monolithic wingwalls interfere with rigid frame action.

There is reason to believe that in both simply supported and rigid frame spans, complete separation of wingwalls from breastwall will be successful. Best results are to be expected with the vertical joint as in Fig. 6*a* and a joint type similar to that in Fig. 24 (page 25). It is advisable to arrange an offset as indicated at the joint in Fig. 9 to conceal possible relative movements at the joint. The joint position in Fig. 6*b* seems less advantageous but if used should be combined with a joint type as in Fig. 25 (page 26).

FIGS. 10 and 11

Horizontal Construction Joints

Cracks at the ends of the bridge seat may be avoided by placing a joint *vertically* as shown in Figs. 6*a* and 9. In Figs. 10 and 11, however, a *horizontal* joint is made level with the bridge seat. The abutment is first constructed up to a level flush with the bridge seat; then the deck concrete is cast; and finally the fillet wall (Fig. 10) or parapet and fillet walls (Fig. 11) are cast. This joint layout has been used successfully by at least one state highway department. It provides an offset at the joint and dowels extending across it. It is also advisable to place a strip of membrane waterproofing behind the joint, to provide horizontal reinforcement below the



FIGS. 10-11 Constructions used to eliminate cracking in abutment at end of bridge seat. The abutment proper stops level with the bridge seat. Parapet and fillet walls are cast after the deck is placed.

level of the bridge seat, and to place a soft joint filler in the vertical joint between fillet wall and deck. The relative movements of the deck will not seriously affect the abutment proper. The only damage that may be done under unfavorable conditions will be confined to the fillet or parapet walls and will be insignificant.

The use of a horizontal construction joint is also illustrated by the dotted lines in Fig. 7. In this case, the cracks would undoubtedly have followed the horizontal joint and little or no damage would have been done.

FIG. 12

Example of Wingwall Design

Fig. 12 shows a straight wingwall abutment embodying interesting features. This layout facilitates future widening, an important consideration in modern bridge building. The wingwall is a direct extension of the breastwall and the copings are stepped-off to form a good surface for future extension. Where there is danger of erosion, a small return wall is often built at the end. Wingwalls as illustrated here are built with a construction joint at the level of the bridge seat, similar to the construction shown in Figs. 10 and 11. The bridge seat in Fig. 12 is stepped-off to maintain a constant girder depth under a crowned or superelevated roadway. (See also Fig. 51.)

FIG. 13

An abutment of this type recently built by the Ohio State Highway Department is shown in Fig. 13. It features the use of horizontal grooves—rustication—on part of the front face. Rustication conceals construction joints and enhances the general appearance.

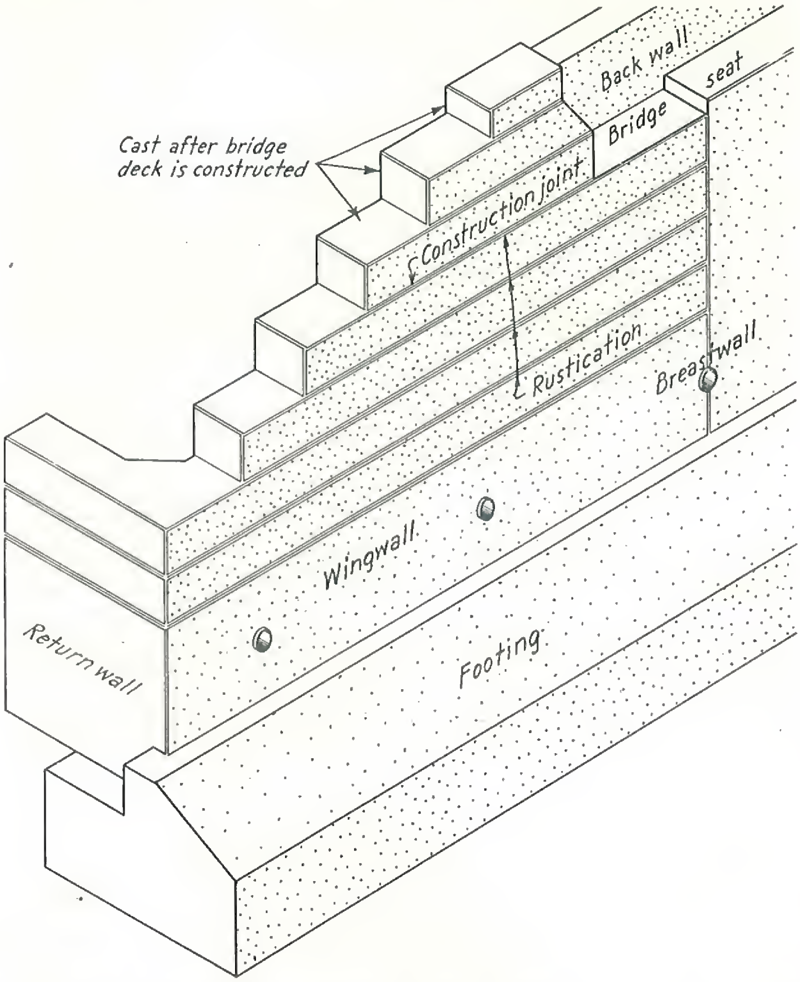


FIG. 12 Abutment design used by Ohio State Highway Department embodies these advantages:
Straight wingwalls can be widened with little waste.
Stepped-off coping facilitates connection with future extension.
Return wall prevents erosion of fill behind abutment.
Rustication conceals construction joints.
Stepped-off bridge seat makes girders identical in depth. (See also Fig. 51.)

FIG. 13 Rustication on abutment having straight wingwalls with stepped coping. The fourth groove from the top conceals a construction joint. The concrete above was cast after the deck was placed.

BRIDGE SEATS

The tops of the breastwall—the bridge seats—are built to transmit either vertical loads, or horizontal as well as vertical loads, or these two types of load together with bending moments. They are referred to, accordingly, as having expansion bearings, fixed bearings, or rigid corner connections.

FIG. 14

A study of the effect of bearing types upon abutment layouts for single span concrete bridges is presented diagrammatically in Fig. 14. The customary arrangement shown by *a* in Fig. 14 has one fixed and

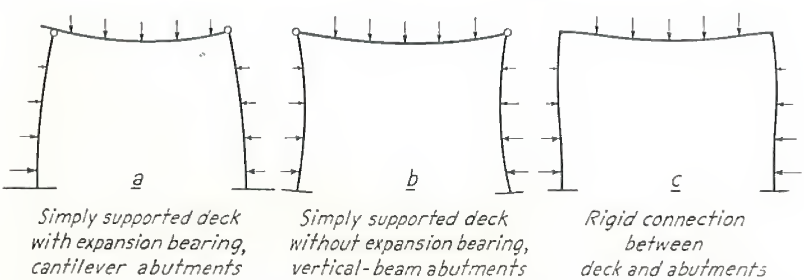


FIG. 14 Diagrams illustrating three types of layout applicable to single span bridges.

one expansion bearing. The abutments are assumed to act as cantilevers, but this assumption is frequently unjustified and considerably in error. Many bridges built according to *a* behave as shown in *b*, in which the deck has two fixed bearings. Abutments, therefore, may act as vertical beams supported horizontally by the deck and by the foundation, and should be so designed. Layout *c* shows a modification of *b*, in which the corners have been made rigid. In comparison with the conventional layout, *a*, the second type often is more satisfactory in service and may even be lower in first cost.

FIG. 15

Typical Seat—Rigid Frame

The rigid connection between deck and abutment shown in Fig. 15 is typical for rigid frame bridges. It consists of monolithic concrete proportioned for shears and bending moment as determined by the analysis. Longitudinal reinforcement only is indicated here. Sufficient transverse reinforcement must be added to provide for shrinkage, torsion and unequal settlement.

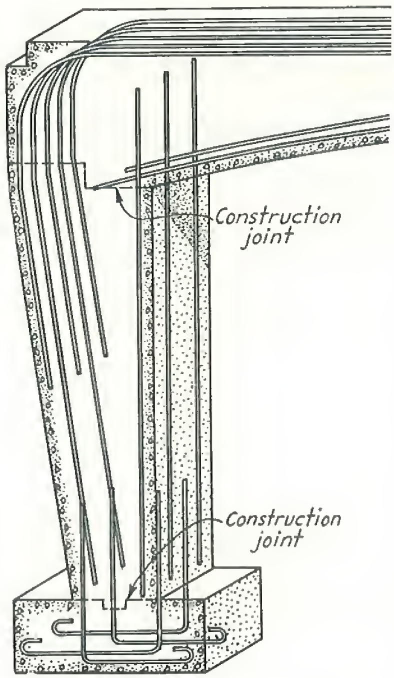


FIG. 15 Typical connection between deck and abutment in a rigid frame bridge. Main reinforcement only is shown. Transverse reinforcement also essential.

FIG. 16

Fixed Bearings at Both Ends of Deck Girders

The Wisconsin Highway Commission has had success with the fixed bearing detail shown in Fig. 16 which has been used for years at *both* ends of concrete girder bridges with span lengths up to 45 feet. The abutment is cast up to a simple construction joint as indicated at the top of the abutment, and dowel bars are extended above the joint. The end of the deck is then cast directly on top of the concrete in the construction joint. The dowels are not designed or located to resist any bending. A horizontal strip of membrane waterproofing placed behind a construction joint will prevent leakage of water into and through the joint. It would be better to make the joint follow a straight horizontal line flush with the bottom or

soffit of the deck girders.

Another detail for bridge seats with fixed bearing is shown under *Joints in Decks.*

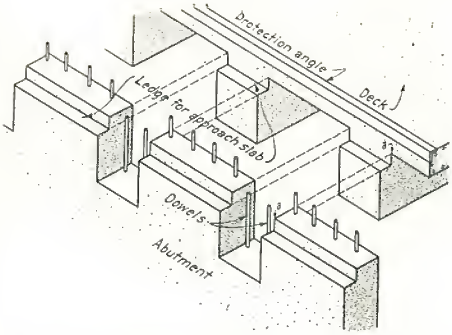


FIG. 16 Bridge seat used by Wisconsin Highway Commission. The deck and the abutment are not shown in their proper relative position, but the dotted lines and a-a indicate how deck and abutment fit together.

FIG. 17

When the spans are long, say 50 feet or more, the deflection of the deck may rotate the ends of the girders so much that the bearing pressure may become concentrated on a narrow strip along the front edge of the seat and cause local damage.

Bearing Plates

Double steel plates, as illustrated in Fig. 17, are suitable for long girders. The top plate is fastened to the superstructure and the bottom plate to the bridge seat. One plate has a convex bearing surface, so that it can rock on the other as the girders deflect. Sliding between plates may be prevented by use of heavy pins tapped into the bottom plate and extending through conical holes in the top.

Expansion Bearing Details

Various details are used at expansion bearings. Layers of tar paper are often the only expansion device inserted between the bridge seat and the deck. The efficiency of this detail is questionable, as it has been observed that a number of tar paper expansion bearings show no evidence of consistent relative movements.

Two plane plates attached to the bridge, one to the seat and one to the deck, are also used at expansion bearings—often separated by a thin layer of materials such as graphited asbestos, zinc or copper to reduce friction. For long spans a detail similar to that in Fig. 17—consisting of a plane and a curved steel plate, but without pins—may be suitable. A construction using a roller or rocker placed between two steel plates has the advantage of insuring more positive and longer lasting freedom of movement.

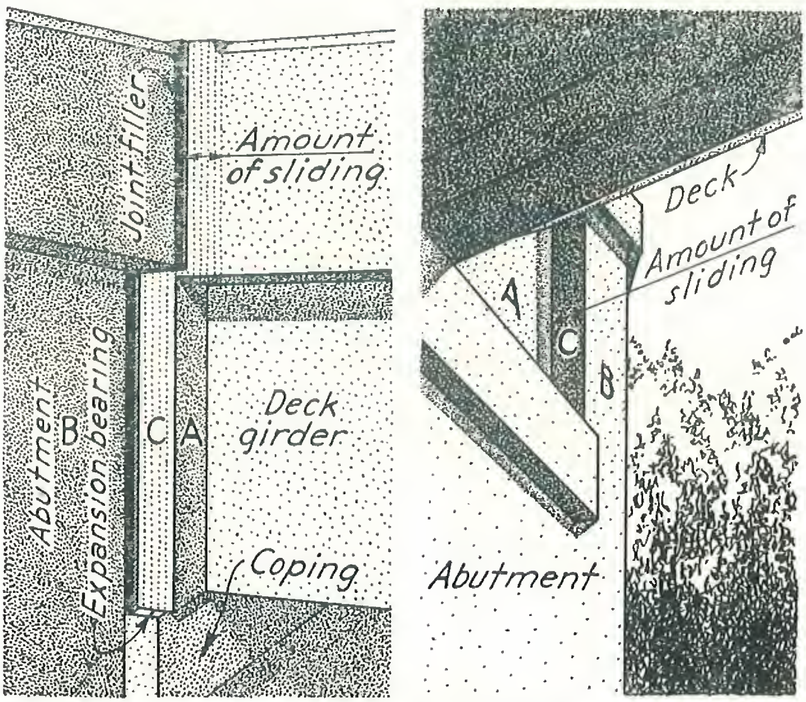
FIG. 17 Bearings on pier illustrating the use of plane and convex bearing plates. Quite evidently these plates were not accurately placed.

Importance of Freedom of Movement

There is considerable doubt as to the permanency of the freedom of movement in many types of expansion bearing. Corrosion of the metal or decomposition of other materials may ultimately interfere with the regular sliding action. The expansion bearings are then said to be "frozen" and the structure behaves as if the deck had fixed bearings. This condition is relieved somewhat by the use of cast iron or non-corrosive metals such as stainless steel and bronze alloy.

Protecting the Bridge Seat

The bridge seats should be kept free from dirt and moisture from the approach fill. At fixed bearings this may be accomplished by placing a strip of membrane waterproofing on the rear face of the abutment. Both the angular and horizontal movements here are so small that there is no danger of rupturing the fabric. In other cases, the breastwall is extended up past the end of the deck. Details involved in this type of construction are discussed under *Joints in Decks*.



FIGS. 18-19 Sketches showing relative movements at expansion bearings. The surface marked *A*, which is part of the deck, was originally flush with the surface marked *B*, which is part of the abutment. The abutment then moved and created an offset between *A* and *B* as indicated by the area marked C. The deck slid on the expansion bearing, the amount of sliding being indicated by the arrows. The abutment has moved backward in Fig. 18 and forward in Fig. 19.

Stepping-off the Seat

Bridge roadways are usually crowned, and it is often desirable to build all deck girders of equal depth under the roadway to simplify bar details and formwork. It is expedient in such cases to step off the bridge seat as shown in Fig. 12. This detail is discussed further under *Creep in Skew Bridges.*

Cantilevered sidewalk slabs should usually be separated from abutments by wide joints filled with a soft joint filler. Otherwise the slabs may crack.

ABUTMENT MOVEMENTS

Vertical and horizontal displacement of the footings causes relative movements of abutments with respect to the deck. This creates critical strains in the abutments, in addition to the strains caused by structural action already discussed.

It is usually difficult to ascertain by field inspection whether and how each abutment moves. The only visible evidence of movement is at the expansion bearing, and this shows only the combined movement of both abutments. The most common movement of an abutment, of course, is forward toward the deck.

FIGS. 18 and 19

Evidence of Movements

Fig. 18 shows how abutments may move relative to the deck. Here backward movement of one or both of the abutments is indicated. Evidence of forward movement is presented in Fig. 19. The width of the dark area of shadow (C) represents the total movement in both abutments. The original clear distance between the abutments has evidently been shortened by about 4 inches.

It is probable that the deck in Fig. 19 now bears against the backwall of the abutment. If so, no further movement will take place, but at the same time the expansion bearing will act partly or even wholly as a fixed bearing. The structure will then behave not according to type *a* in Fig. 14 but as type *b*, and the abutments will act as vertical beams or slabs supported by the deck and by the footing.

FIG. 20

Deck Jammed between Backwalls

It is usually difficult to detect cases where concrete decks are jammed between the abutments, and attempts to release the deck are rarely made in concrete structures. In some cases involving other types of structures, the deck was observed to be wedged tightly between the backwalls of the abutments, thus creating a horizontal thrust in the deck structure. Fig. 20 illustrates a case in which the backwall is punctured in order to relieve the deck

Wet and Dry Backfill Pressure

of the thrust and permit it to "breathe."

Abutments are usually proportioned to withstand the active earth pressure from *dry* backfill only, assumed to be equivalent to the pressure exerted by a fluid weighing 30 pounds per cubic foot.

If the backfill behind the abutment becomes saturated, it will exert a pressure which may be more than twice as great as that assumed in the design. As a result, the abnormally high pressure of *wet* backfill causes harmful effects by making abutments tilt or move forward as a whole. For this reason, backfills generally should not be jetted but should be placed and compacted without the use of water.

FIG. 20 Abutment backwall purposely punctured to allow the superstructure to "breathe." Evidence of inward movement of abutments is seen at the expansion bearing.

Precautions

The following precautions should be considered where movements of abutments are anticipated. The front face of the abutment should be given a slight batter in order to avoid the ugly appearance accompanying a forward tilt. The backfill should preferably be of a coarse material or any other material that quickly releases entrapped water. The abutment should be designed as usual as a cantilever and also in many instances as a vertical beam supported at the foundation and at the bridge seat; this requires vertical bars at both faces. It may be advisable under unfavorable circumstances to make a special investigation of the stability of the abutment for an earth pressure 2 or 3 times greater than the active pressure assumed to be exerted by dry backfill.

JOINTS

The correct location and proper construction of joints are of great importance in bridge building. The ordinary concrete bridge structure is composed of various elements, each of which may expand or contract. In addition, adjacent elements may have a relative movement which is often imperceptible but may become destructive if the joints are not properly designed.

A construction joint is created where the casting of the con-

crete is temporarily discontinued. Designers should show the position of the construction joints on the drawings, and no additional joints should be allowed in the field except by special permission.

It was often observed during the survey that water seeped through horizontal construction joints in abutments, that the seepage had caused damage, and that concrete abutments without joints were more durable. If horizontal construction joints must be used, and the concrete is placed in "lifts," special precautions must be taken. Additional dowels should be placed across the joint and a strip of membrane waterproofing should be placed behind the joint. Most important of all, the concrete must be uniformly dense and non-absorbent throughout the entire height of each lift. It is best, whenever possible, to avoid having any horizontal joints in abutments between the bridge seat and the top of the footing.

In case a coping is used immediately below the bridge seat, the concrete should be placed up to the underside of the coping and concreting then discontinued for a time only sufficient to permit the concrete to settle before the coping is cast. This, however, does not constitute a regular construction joint.

FIG. 21

Construction joints should have a small groove on all exposed surfaces wherever possible. This will make the joint neater and prevent spalling. Fig. 21 illustrates the typical appearance of a construction joint that is left plain compared with one that is grooved. Note the superior appearance of the grooved portion.

Joints other than ordinary construction joints may be classified either as "contraction joints" or as "expansion and contraction joints." The simple terms "contraction joints" and "expansion joints" are often used. Different modifications of these joints are used in abutments, decks and handrailings.

FIG. 21 Note the contrast between the unsightly ungrooved portion of this construction joint and the neat triangular groove.

JOINTS IN ABUTMENTS

To prevent seepage, all construction or contraction joints should be protected by a strip of membrane waterproofing. The fabric will not tear because the reinforcement is continuous across the joint. Fabric waterproofing should not generally be used at expansion joints; seepage must here be prevented by other means.

FIG. 22

Plain or Keyed

For contraction joints in abutments, the plain grooved type—*a* in Fig. 22—is usually adequate. If there is any danger of relative horizontal movement or sliding, a key-and-groove joint as shown by *b* in Fig. 22 is preferred.

The small groove illustrated in Fig. 21 appears from observation to be adequate. If an appearance involving rustication is desired, a larger groove is often used, as indicated in Fig. 12 (page 16). White lead paint is sometimes brushed on the concrete in places where it is desirable that a construction joint should open.

The plain joint and the key-and-groove joint shown in Fig. 22 are usually the only types that are needed in breastwalls less than 50 feet in length. It appears that normal contraction of the concrete can be accommodated if the joints are spaced not more than 15 to 20 feet apart.

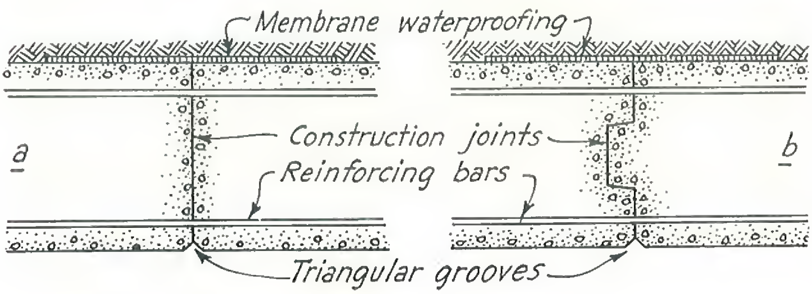


FIG. 22 Horizontal sections of a plain and a key-and-groove construction joint used in abutment walls. The reinforcement extends across the joint.

FIG. 23

Doweled Joints

The modification of this type of joint shown in Fig. 23 is sometimes used and with good results. Short dowels, about 60 diameters long, are the only reinforcing bars that cross the joint. One-half of the length of the dowels is embedded in the concrete first cast; the other half of the dowels is either greased or placed within

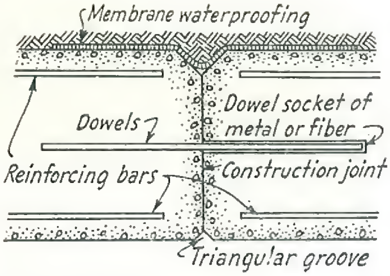


FIG. 23 Horizontal section of vertical construction joint sometimes used in abutments. The dowels are bonded to the concrete on one side only.

thin-walled tubes (of metal or fiber) before concreting is resumed. The width to which the crack may open is not restrained by any reinforcing bars except by those in the footing. The membrane waterproofing may therefore tear unless it is placed with a fold at the joint as indicated in Fig. 23, or two separate strips may be overlapped at the joint. The action of the dowel bars in this detail is similar to that of the key-and-groove construction shown in Fig. 22*b*.

FIG. 24

Expansion vs. Contraction Joints

The typical feature distinguishing an expansion joint from a contraction joint is that the concrete in the latter is cast directly against concrete in the joint, whereas in the expansion joint the abutting concrete surfaces are separated by a filler. The function for which the joint is designed determines the thickness of the filler; it is usually between ½ and 1 inch. The expansion joint is suitable for cases in which expansion as well as contraction is anticipated. It should be observed that "expansion" in abutments is rarely due to swelling of the concrete but is caused by movements such as creep or settlement.

A Watertight Joint

In abutments, the watertight expansion joint construction shown in Fig. 24 is usually satisfactory. The exposed edges should be chamfered and seepage prevented by inserting a bent strip of 16-ounce copper plate. The copper strip may be placed as in *a* to prevent water from penetrating the joint. A neater appearance is obtained by placing the copper as in *b*.

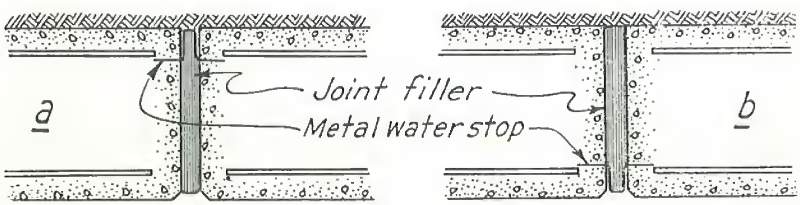


FIG. 24 Horizontal sections through expansion joints suitable for use in abutments.

FIG. 25

The key-and-groove construction may be incorporated in the expansion joint detail as shown in Fig. 25. The lip outside the groove has been known to be damaged by cracking along the dotted line shown. Care should therefore be taken to make the lip sufficiently thick and to reinforce it properly.

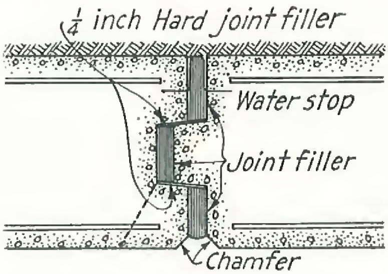


FIG. 25 Horizontal section through expansion joint with key-and-groove construction.

JOINTS IN DECKS

It is now generally agreed that water must be kept from seeping through joints in decks. This requirement has in the past been violated in a great many cases.

FIG. 26

Importance of Preventing Seepage

Seepage is commonly observed and water stains often mar the beauty of bridges, as illustrated in Fig. 26. Moreover, failure to

FIG. 26 Seepage through deck joint has caused unsightly water stains and may damage the pier cap. This illustrates the need for proper joint details.

prevent seepage through joints and cracks is responsible for a good deal of local damage in otherwise durable structures.

Drenching of ordinary concrete due to rain is not harmful. For illustration, the handrailing in Fig. 26 shows no evidence of disintegration or signs of water stain. It is slow and constant seepage that may be harmful. Good, dense concrete is durable even when constantly or intermittently wetted, but inferior porous concrete may be damaged by slow seepage. Concrete mixes with low water-cement ratio* are essential for exposed structures since such mixes are dense and practically non-absorbent.

Most Destructive Conditions

Especially destructive is the combination of conditions in which (1) constant seepage takes place through a (2) porous concrete where the climate has (3) frequent cycles of freezing and thawing. Prevention of local damage therefore depends upon the two following safeguards: seepage through joints and cracks should be prevented, and the concrete must be made dense and non-absorbent.

FIG. 27

Construction joints in decks should be avoided as much as possible. If used, they should be detailed so that they do not develop cracks through which water may seep. They should preferably be placed along lines crossing the greater amount of reinforcing bars. It is particularly advisable to add dowels across the joint near the top surface as shown by *a* in Fig. 27 in order to help the regular reinforcement keep the crack closed. The edges should have a small bead, as in *a*, to prevent scaling. The groove

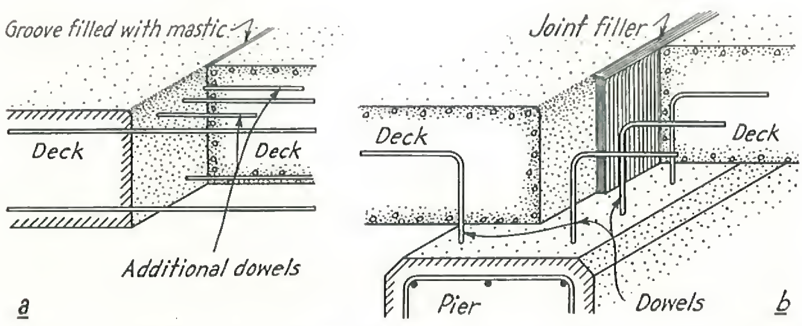


FIG. 27 Joints suitable for concrete decks. The joint in type *a* may be keyed and is used where the reinforcement is continuous, while type *b* is used where the reinforcement is not continuous.

*A complete discussion of the basic principles involved in making durable concrete is given in "Design and Control of Concrete Mixtures" available upon request to the Portland Cement Association.

should finally be covered with mastic. A key-and-groove joint is often specified.

Adjacent Fixed Bearings

In Fig. 27, *b* represents a joint between two simply supported deck spans with adjacent *fixed* bearings on the pier. Although the two decks have no relative horizontal movement, it is inadvisable to omit the joint filler. The reason is that the deflection of the spans may rotate the ends of the decks and thus open the joint sufficiently to admit water, and yet the crack may be so small that it is difficult to calk. The use of a thin sheet of joint filler (*b* in Fig. 27) is preferred. As the need arises, the filler may be driven tightly into the space between the abutting concrete surfaces. The use of a small bead on the edges is good practice.

FIG. 28

Expansion Joint at Piers

The number of deck expansion joints should be kept as low as possible—for example, by judicious arrangement of fixed and expansion bearings in multi-span bridges.

Three major requirements must be fulfilled at expansion joints. Sufficient space must be provided for relative movements; the gap between adjacent sides of the joint must be bridged in order to avoid roughness in the wearing surface; and water must be kept from leaking through the joint.

Treadplates

The two joints sketched in Fig. 28 are representative of the type found to be serviceable for use in bridge decks. Detail *a* in Fig. 28 is suitable for use in sidewalks or pedestrian bridges. It embodies

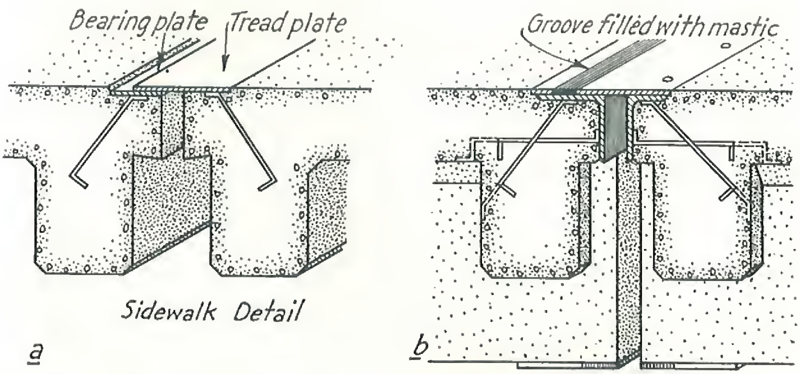


FIG. 28 Two types of devices used at expansion joints in concrete decks. Type *a* has been used successfully on sidewalks, while type *b* is preferred on roadways.

two plates—a treadplate and a bearing plate—anchored to the concrete on opposite sides of the joint. The attachment of the plates, *a* in Fig. 28, is not sufficiently substantial for use in roadways. Detail *b*, embodying two plates and two angles, is preferred for ordinary highway traffic. Treadplates are preferably attached to the uphill side of the joint, and the groove between the plates is filled with mastic in order to reduce seepage of surface water. Drips indicated at the bottom of the slabs in Fig. 28 may help keep water from running down the sides and across the bottoms of beams and girders. For at least one foot on either side of the expansion joint, the wearing surface should be monolithic.

FIG. 29

Treadplates are often attached to the angle below by means of rivets with heads countersunk in the roadway surface. Some designers recommend the use of tap screws instead of rivets to facilitate removal of the treadplate in case it must be replaced. It is possible, however, that corrosion may prevent the removal of the tap screws. It may therefore be advisable, for future use, to provide some intermediate threaded holes in the angle and to fill the holes with grease. The appearance of an expansion device similar to *b* in Fig. 28 is illustrated in Fig. 29.

Allowance for Expansion

Great care is required in planning expansion joint details. First of all, it should be ascertained that sufficient space is provided throughout the deck for movements that may take place in the joint. The handrailing, for example, should be so constructed that there will be no contact across the handrail joint even if the deck joint is completely closed. The girders should always be so built that they will bear against each other before any other contact is possible. It is important that the metal shapes be carefully placed and securely attached so as to avoid roughness in the roadway surface. The treadplate should be made to bear tightly against the metal shape underneath, since failure to do so often causes the metal shapes to become loose and rattle.

FIG. 29 Treadplate at expansion joint in concrete deck slab. This deck has one-course slab without separate wearing surface.

FIG. 30

The joints at the ends of the deck must be detailed to fit into the entire layout at the top of the abutment. There are three main elements to consider: namely, the support of the approach slab (usually of reinforced concrete), the support of the deck (which is either a fixed or an expansion bearing, but preferably a fixed bearing), and watertightness of all joints involved.

Deck Joint at Fixed Bearing

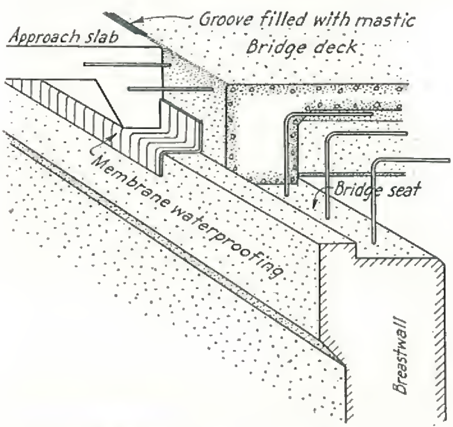


FIG. 30 Isometric view illustrating bearing arrangement at the fixed end of a concrete deck. The horizontal dowels across the vertical joint may be bonded to the deck concrete only.

Fig. 30 shows an arrangement for a deck supported by a fixed bearing on the seat of an abutment. Dowels between the deck and the breastwall make it a fixed bearing, and the ridge on the bridge seat acts to counteract the tendency of the abutment to move inward under the deck. The strip of membrane waterproofing is added to insure watertightness in the horizontal joint. Some designers recommend the use of vertical dowels tying the approach slab to the seat to prevent the approach from being lifted off its seat when the slab is jacked up with a mud-pump. It appears that the vertical dowels will interfere with the placing of the membrane waterproofing. It is therefore suggested that they be placed horizontally as indicated in Fig. 30. This arrangement has the added advantage of helping to keep the vertical joint closed and watertight. If the dowels are omitted, the use of a joint filler is recommended for watertightness. In Ohio, the Bureau of Bridges successfully uses fixed supports similar to that of Fig. 30 at *both* ends of slab deck spans up to 25 feet long. In the case of deep deck girders, the construction in Fig. 30 may be modified to allow a bearing ledge in the deck for the approach slab.

FIG. 31

The details are different when the deck is allowed to move longitudinally on an expansion bearing. It is then necessary, in order to keep the bridge seat clean and dry, to provide a backwall

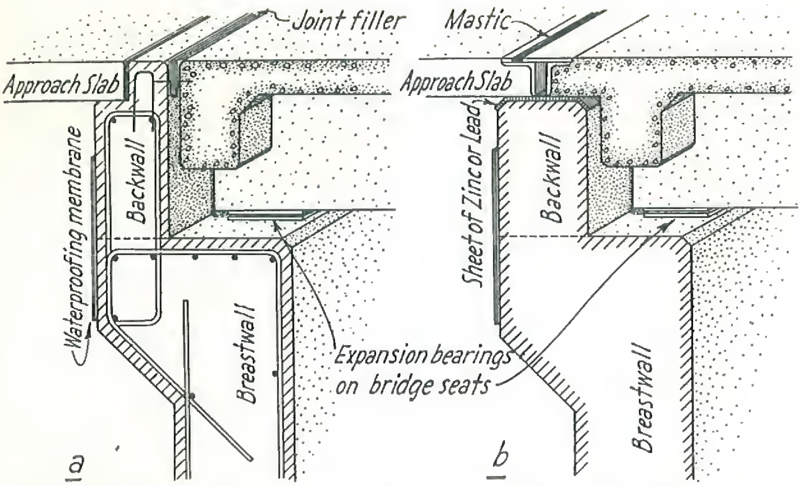


FIG. 31 Two arrangements of joints at the expansion end of concrete decks. The backwall is extended to the roadway surface in type *a*, while it stops at the bottom of the slabs shown in type ***b***.

Deck Joint at Expansion Bearing

by an extension of the breastwall up past the end of the deck as shown in Fig. 31.

When the top of the backwall is at the bottom of the approach slab, as shown in *b*, Fig. 31, only one joint appears in the deck. Deck expansion devices similar to those in Fig. 28 may be used to bridge the gap in the joint, or a simple joint may be used. The joint is placed near the middle of the backwall, the deck slab is cantilevered backward to this joint, and a sheet of lead or zinc (bent as shown) may be used under the two slabs to reduce the friction.

The construction in which the top of the backwall is made flush with the roadway surface is also commonly used, but makes two joints in the roadway surface. The main joint (at the deck) is usually of the type embodying joint filler and copper strip for watertightness.

FIG. 32

The water stop may be one of the types shown in Fig. 32. The secondary joint at the approach slab needs only a thin sheet of joint filler. The use of the copper strip at deck expansion joints that close and open at frequent intervals has been unsatisfactory in some instances. The copper was found to be cracked due to fatigue from being frequently bent in opposite directions. For this reason it may be advisable to use a construction without water stop

and to give preference to a detail similar to that shown in Fig. 31*b*. It should be noted that water stops of the type in Fig. 32 are satisfactory for expansion joints in abutments where the movements are so small and infrequent that there is little chance of rupture due to fatigue.

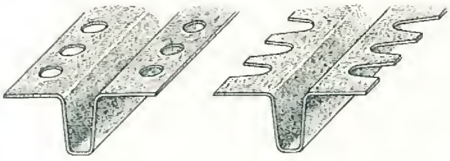


FIG. 32 Two types of water stops that are used to make joints watertight. The perforations are designed to permit greater bond between the concrete on the two sides of the sheet.

DRAINAGE

Crown and Gutter Grade

Surface water on bridge decks should be disposed of as quickly and directly as possible. This is accomplished by crowning the roadway and building gutters to drain into inlets.

All bridge decks not superelevated should have a crown. A 1¼-inch crown in 20 feet of roadway width is usually sufficient. For widths equal to W (in feet), the rise of the crown (in inches) may be made equal to $1\frac{1}{4} + \frac{1}{8} \times \frac{W\text{-}20}{2}$. In general, the crown on a bridge shall be consistent with that on the adjacent highway.

Sufficient pitch in the gutter can be obtained in several ways. The roadway on the bridge may be built on a grade, or with a longitudinal camber, or the pitch may be built into the gutter itself. Some designers prefer always to build bridges with greater longitudinal camber than that required to offset the load deflection. They maintain that it improves drainage and imparts a definite impression of strength by killing the appearance of sag.

Inlets

The drain inlets should be spaced to suit the general layout and should be so constructed that the water is not discharged against beams, girders, piers or abutments. Neither should water be permitted to seep along the bottom surface of the deck.

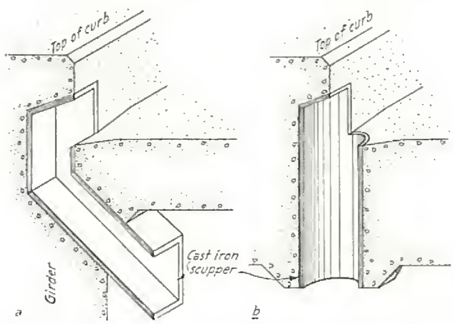


FIG. 33 Two types of scuppers used for drain inlets. The shape of the scuppers is designed to prevent the drain water from touching the concrete.

FIG. 33

Fig. 33 shows typical details of cast iron scuppers commonly used for drain inlets. A clean discharge is obtained in Fig. 33*b* by extending the scupper a few inches below the deck. The scupper should never be stopped flush with the bottom of the deck. The direction of the water discharge may be controlled by use of a scupper type as shown in *a*.

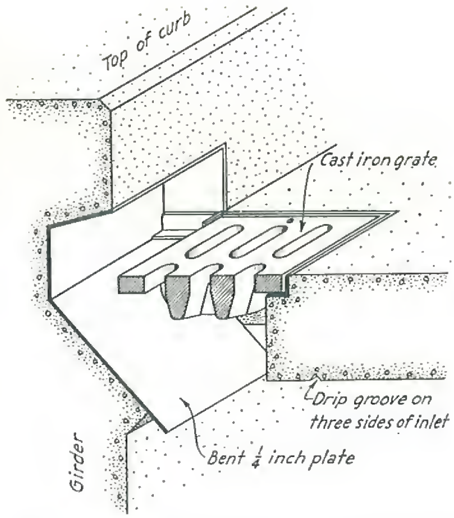


FIG. 34 Self-clearing type of drain inlet with grate and scupper.

In some instances water has been removed from the gutter by placing horizontal drain outlets through the curb, thus discharging the water over the surface of the fascia girders. This improper practice is being definitely discouraged by the Bureau of Public Roads.

FIGS. 34 and 35

The drain inlets shown in Fig. 33 are often considered too small, especially where there is danger of the inlets becoming clogged with ice. The construction sketched in Fig. 34 is then preferred. It combines an overflow arrangement with a large opening covered with a detachable cast iron grate. This type of inlet rarely becomes clogged. Note that the steel plate at the overflow is so constructed that drainage water is deflected away from the girder.

This type of drain inlet is also illustrated in Fig. 35.

FIG. 35 Drain inlet with large grate and overflow arrangement. Note that tap screws attach the grate to the frame underneath.

FIGS. 36 and 37

Disposing of Surface Water

Water should not be discharged upon a railroad bed,

FIGS. 36-37 Concrete gutter and sodding protect embankment slopes against erosion. Eroded slopes detract from the appearance of bridge structures.

roadway, sidewalk, or earth embankment slope around the abutment. If necessary, concrete troughs should be built on the slopes under the drain inlets to avoid erosion. It is good construction to extend deck curbs and gutters along the approach roadway to a point where the drain water may be safely taken down the slopes in concrete lined gutters, as illustrated in Fig. 36. Erosion due to inadequate provision for drainage on the approaches is commonly observed (see Fig. 37) and is unsightly.

Rip-rap on the embankment slopes below the normal water line, and sodding above it, will lower the cost of upkeep and improve the appearance of the bridge.

WEARING SURFACE

Various Types

There is a noticeable dissimilarity in the present practice of applying waterproofing and providing the wearing surface on top of the structural slab. The following constructions are used: (1) Slabs without wearing surface. (2) One-course construction in which the wearing surface (usually less than 1 inch thick) is cast monolithically with the structural slab. (3) Wearing surface cast directly on top of structural slab using two-course construction. (4) Wearing surface separated from structural slab by waterproofing

without fabric. (5) Wearing surface separated from structural slab by membrane waterproofing.

The cost increases approximately in order from type (1) to (5). Observations in the field indicate, however, that the durability *decreases* in the same order. Type (1), for example, appears to be the most durable and at the same time the most economical construction. The Bureau of Public Roads feels that additional thickness for wearing surface is unnecessary except possibly in a few cases such as in regions where there is considerable heavy chain traffic during particularly long periods.

Separate concrete wearing surfaces are built with an average thickness of about 4 inches. If the finished surface is to be crowned, the top of the structural slab is usually given the same crown.

Location of Joints

It has been customary to construct joints in the wearing surface at the following places: (a) along the centerline of the roadway, or between the lanes on bridges with more than two lanes; (b) over the regular deck joints, and transversely at intermediate lines in some cases on long spans. In such cases, the total length of the joints in wearing surfaces is therefore increased over the length of joints in the structural slab underneath. This is an objectionable feature since deck joints are relatively weak and apt to be damaged. The tendency now is therefore to use as few joints as possible in the wearing surface.

Causes of Cracking

The main sources of damage are (a) impact due to wheels passing the joints, and (b) curling of the separate wearing surface in the vicinity of the joint. Free water between the two courses near the joints was observed during the removal of a top course. It was evident that the water had seeped through the joints in the top course and had penetrated through some distance adjacent to the joint, the water being retained on top of the waterproofing. The consequence was that the top course shrank non-uniformly so that its top surface became slightly concave. Freezing of the entrapped water may have contributed to this condition. The curling was most pronounced at the intersection of two joints because the seepage was greatest. The load and impact from passing vehicles then broke the corners.

Advantages of Monolithic Wearing Surface

Curling and seepage are eliminated when the wearing surface is built monolithically with a structural slab or omitted entirely. That is why the one-course bridge deck is more durable than the two-course construction. If two courses are used, care should be taken to develop the best possible bond.

Observations made during the survey pointed to the conclusions that (1) cracking in one-course construction is negligible and

(2) cracking occurs most frequently in the construction consisting of two courses separated by waterproofing.

The use of monolithic or one-course deck construction, despite its economy and durability, has not yet become universal. In this connection it should be observed that separate wearing surfaces are used, not primarily as a means whereby bridge decks may be waterproofed, but mainly in order to facilitate the construction operations. Excellent workmanship, however, was observed in a great number of bridge decks with one-course construction; the lines were true and the surfaces even.

HANDRAILINGS

No part of a bridge is more conspicuous and at the same time more exposed to variations in temperature and moisture than handrailings. Careful attention should be given to their detailing and construction, to which the following rules are considered generally applicable.

FIG. 38

Esthetic Considerations

A pleasing proportion between the general aspect of the railing and the bridge proper is esthetically desirable. For example, a

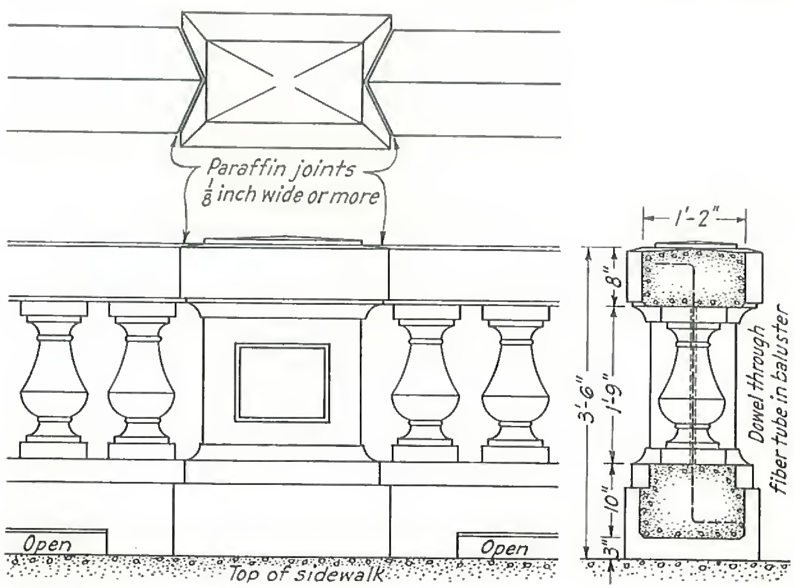


FIG. 38 Handrailings with precast spindles are often preferred and have a pleasing appearance.

solid handrailing is preferred for spandrel filled arches while the open railing type is better suited for use on open spandrel arches. According to the same rule, a well balanced appearance is obtained by using an open railing on the span over the bridge opening and a solid railing on the wingwalls. Handrailings with precast spindles as shown in Fig. 38 and Fig. 39 are particularly suitable for bridges in urban regions.

FIG. 39 Handrailing on two-span arch bridge. The post over the pier is carefully jointed on each side. Note the wind-slot below the footrail.

FIG. 39

Precast concrete spindles for railings of the type illustrated in Fig. 39 have occasionally been observed to differ in texture from the rubbed surfaces of adjacent cast-in-place concrete. Suitable molds and materials should be chosen for precast spindles in order that their texture may conform to that of the surrounding concrete.

Snow, Smoke, Wind

In regions with heavy snowfalls, handrailings are often designed to be as open as possible to minimize drifts and facilitate snow removal.

The use of solid handrailings is sometimes advocated for spans over railroad tracks in order to prevent smoke from discoloring the inside of the railing. Fig. 40 illustrates an open and a solid handrailing design, the latter being on a span over a railroad.

FIG. 40 Handrailing illustrating open joints, split post, wind-slot, and solid railing over railroad track.

FIG. 40

Some designers advocate the use of an open space between the top of the sidewalk and the bottom of the railing panels as illustrated in Figs. 38, 39 and 40. The draft through the wind-slot thus created has been found to assist materially in keeping the sidewalk free from snow, leaves and debris. The slot is not used in railings placed on curbs.

FIG. 41

It is advisable to delay the erection of handrailings until after the falsework has been struck and the deck has taken the major part of its dead load deflection. This applies particularly to arches with long spans and to all spandrel filled arches. If this precaution is not taken and the joints are made too narrow, compression may be set up in the handrailing. The result may be that the joint filler is squeezed out as illustrated in Fig. 41 or the compression may ultimately cause spalling of the concrete at the joints.

FIG. 41 Handrailing on arch bridge showing extruded joint filler.

Spindle Details

If the spindles are pre-cast, it is not advisable to provide a depressed pocket for them in the top of the footrailing, because water may be retained and may freeze in these pockets. It is better to make the surface plane or even to provide a raised pad slightly larger than the size of the spindle. A dowel bar is usually placed through a hole in the center of the pre-cast spindle as shown in Fig. 38.

FIG. 42

Sharp re-entrant angles tend to start cracking, particularly in

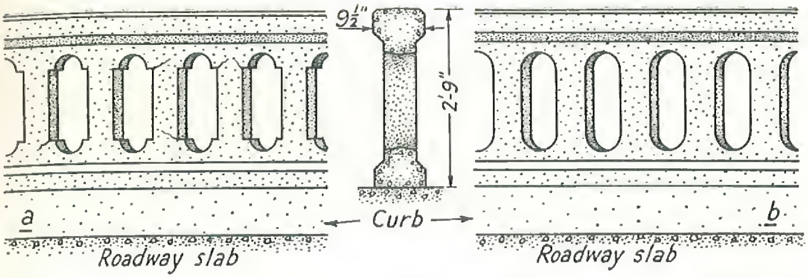


FIG. 42 Handrailing with re-entrant angles may develop cracks as indicated in type *a*. It is better to make the apertures rounded as shown in type *b*.

handrailings, because of severe exposure. For illustration, the type of railing shown in Fig. 42*a* often develops cracks as indicated, and the construction shown in Fig. 42*b* is preferable.

FIG. 43

Design of Panels and Posts

Handrailings are frequently divided into panels by posts spaced about 7 to 12 feet apart. An odd number of panels in a bridge span is esthetically preferable to an even number. The type of post shown in Fig. 43*a* is unsatisfactory both from appearance and durability. A post detail as shown in Fig. 43*b* is better.

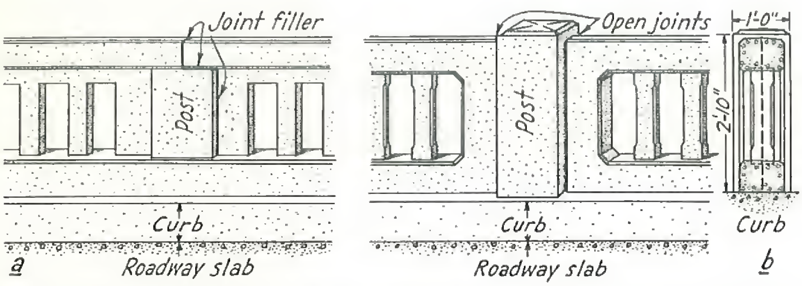


FIG. 43 The post detail in type *a* appears to be too stubby and the off-set joint is objectionable. The post in type *b* has better proportions and has been used successfully with open joints.

FIG. 44

The regions of the railing above the abutments and piers are commonly accentuated by use of an exceptionally large post. The jointing of this post needs careful attention. A common joint arrangement at a pier is to attach the post to one side of the joint

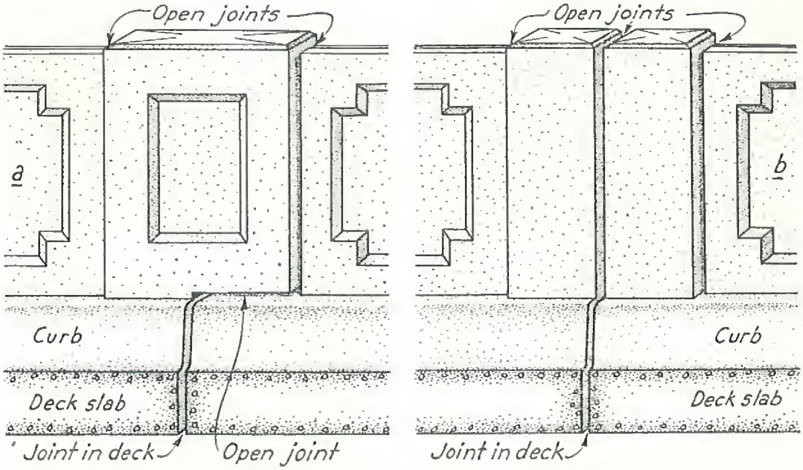


FIG. 44 Post details suitable for use at deck joints over piers and abutments. Type *a* has one undivided post attached to one side of the joint, while type *b* has two posts separated by an open joint.

in the deck and let it cantilever over the deck on the other side of the joint. This is shown in Fig. 44*a* and Fig. 45. Care must be taken to provide sufficient space in the joints, particularly in the horizontal joint above the curb. It is best to make the horizontal joint with an open space about ¾ inch wide. There is now a tendency to avoid the cantilevered type of post and to split the post into two symmetrical halves, each of which is attached to the deck on its respective side. This arrangement is shown in Fig. 44*b* and Fig. 40.

FIG. 45

Types of Joint Filler

The appearance and durability of a handrailing depend a good deal upon the type of material used for joint filler. White lead paint or paraffin brushed on in several thin layers has been used for joint filler in special cases, but such joints are often too narrow. Among other materials used are pre-molded bituminous joint filler, sponge rubber, and cork board. The requirements for good joint filler should be still more exacting than those for joints in abutments, because good appearance is of greater importance in railings. The best results are usually obtained by using no joint filler at all and by providing an open space wherever the railing must be jointed. A ¾-inch width is usually sufficient except at deck expansion joints, where the width should be made at least equal to the width

FIG. 45 End post in handrailing supported on abutment. Note that the horizontal joint above the deck slab is open.

of the joint in the deck. Open railing joints have been used successfully on a great number of bridges.

Lateral Strength

The construction of handrailing with inadequate lateral strength constitutes a distinct hazard, and reasonable strength should be required to prevent automobiles from breaking through the railing. For this reason the Bureau of Public Roads favors the requirement that railings shall be designed to withstand safely a lateral pressure of 500 pounds per linear foot applied to the railing at a point about 2 feet above the roadway surface. For the sake of safety, the Bureau of Public Roads strongly recommends smooth inside surfaces without projections, especially in railings on curbs adjacent to the roadway.

CREEP IN SKEW BRIDGES

Many bridges are built with an oblique angle between the direction of the roadway and the direction of the piers or abutments. These so-called skew bridges have some characteristic features that are generally given little attention in detailing and construction.

FIG. 46

Observed Lengthening of Longer Diagonals

Numerous observations revealed that the longer diagonal of skew bridge decks had a tendency to lengthen during a long period of service. The most distinct evidence was usually observed at the expansion bearing, where the deck had moved laterally upon the bridge seat in the direction toward the acute angle of the deck as indicated in Fig. 46.

Lateral creep has been observed to amount to as much as 4 inches. Even much smaller movements may cause damage. In single-span bridges, for example, the pressure accompanying the

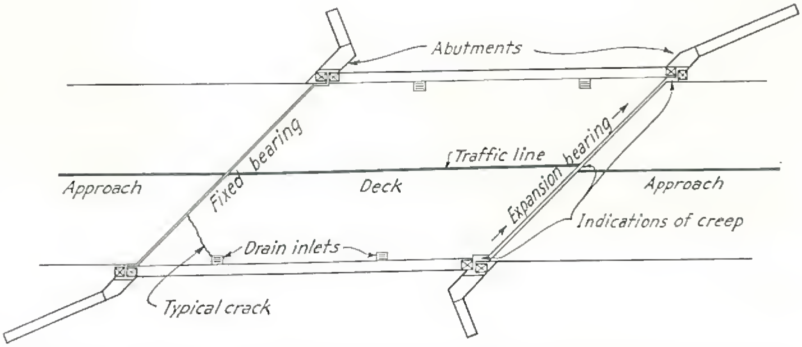


FIG. 46 Plan view of skew bridge illustrating how the long diagonal tends to elongate. The free end then creeps laterally on the expansion bearing as indicated.

movement may be great enough to break a large piece out of the wingwall and displace it several inches. Fig. 47 is a sketch of possible damage to an abutment through failure to prevent creep in a skew bridge. Note that the damage is greatest at the bottom of the abutment where it is restrained from moving.

FIG. 47

Evidence of Creep

It may be significant that the crack at the end of the bridge seat in Fig. 47 resembles very closely cracks *c* in Figs. 3 and 6*a*. The crack in Fig. 6*a* and the damage in Fig. 47 may represent different stages in the development of damage done by creep. Creep may possibly be another reason for cracks like *c* in Fig. 3.

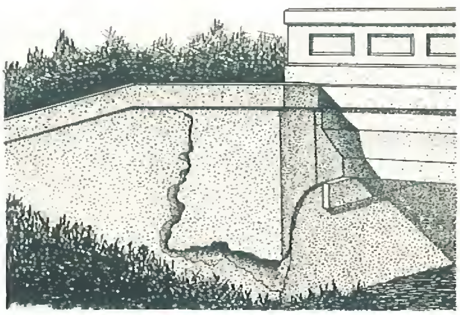
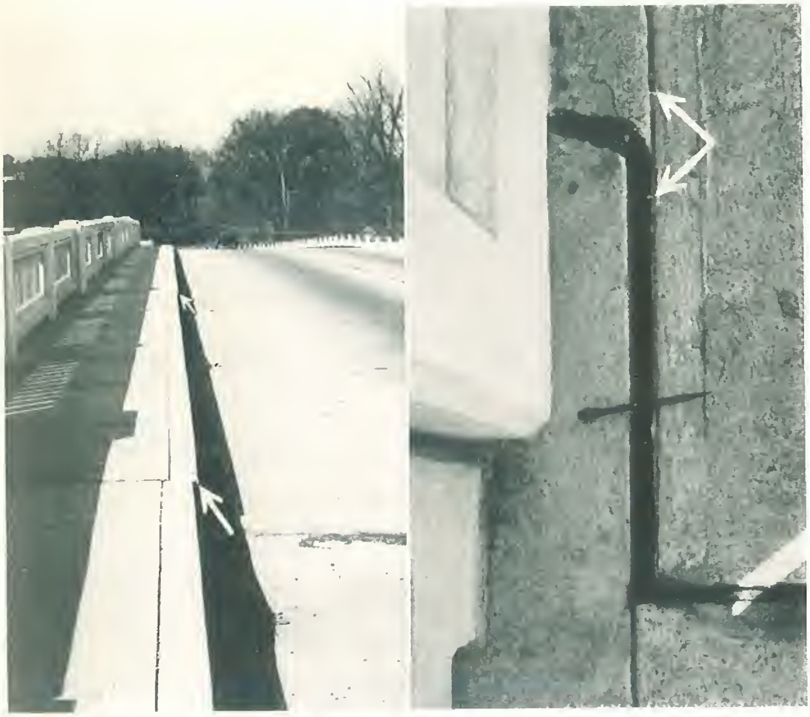


FIG. 47 Abutment damaged by creep at expansion bearing in skew bridge. It is evident that creep is accompanied by great forces.

FIGS. 48 and 49

In some instances, the evidence reveals creep at the expansion bearing of the deck. For illustration, the multi-span bridge shown in Figs. 48 and 49 has one expansion and one fixed bearing on each pier. The offsets in the curb line illustrated in Fig. 48 show a creep of about 1¼ inch in each expansion bearing. This creep can also be observed in Fig. 49, which shows a close-up of part of the joint in the sidewalk on the same bridge.



FIGS. 48-49 Skew multi-span bridge exhibiting creep at expansion supports. Note offset of about 1 1/4 inch in curb at each pier (left) and increase in width of joint in sidewalk (right) both caused by creep.

FIG. 50

The evidence of creep is usually overlooked in the early stages. For example, little attention may be given to conditions such as that illustrated in Fig. 50, which shows that the joint filler has been squeezed out at the acute angle of the deck at the expansion bearing. This was caused by creep. The combined resistance furnished by the friction in the expansion bearing and by the strength of the concrete in the wingwall has apparently been sufficient to check further creep.

Preventing Creep with Fixed Bearings

It is not advisable to disregard the phenomenon of creep in skew bridges or in bridges on curves and thus to permit wingwalls to be subjected to a considerable thrust they are not built to resist. Damage due to creep may be prevented by omitting expansion bearings on abutments. The construction of single span concrete bridges with two fixed bearings has been used for years by the Wisconsin Highway Commission for span lengths up to 45 feet. None of these bridges showed signs of creep.

FIG. 51

Similar methods of preventing creep are used by the Bureau of Bridges in Ohio. Here two fixed bearings are used for slab decks with span lengths up to 25 feet, and another method applying to longer span lengths has recently been adopted. The latter construction is indicated in Fig. 51* which shows a vertical section taken in front of the expansion bearing on the bridge seat. The sketch shows how the center part of the bridge seat is raised so that it forms a block, which acts as a key between the central beams. The deck may move longitudinally, but lateral creep is prevented. This construction has been in use for a short time only but should give satisfactory results. It seems to be a highly desirable detail for use at all expansion bearings in skew bridges or bridges on curves.

FIG. 50 Extruded joint filler indicates creep at the expansion end of a skew bridge. Indications are that further creep will become destructive.

Suggested Practice in Bearing Layout

In view of the discussion in this section, as well as in preceding sections, the following rules appear to warrant considerable attention:

1. In single-span layouts, use two fixed bearings on the abutments when the span length does not exceed 45 feet.
2. In two-span layouts, use fixed bearings on the abutments and expansion bearings on the pier.

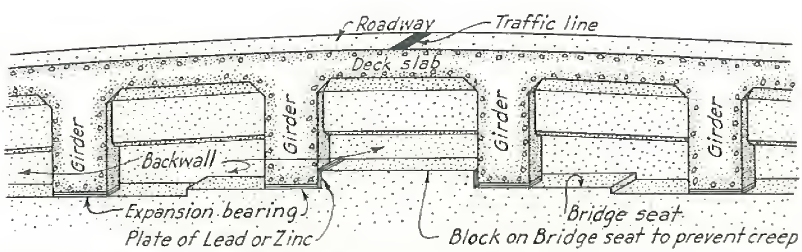


FIG. 51 Vertical section through deck shows expansion bearing in which creep is counteracted by raising the central portion of the bridge seat.

*Not drawn to scale.

3. In three-span layouts, use fixed bearings on the abutments, two fixed bearings on one pier, and two expansion bearings on the other pier.
4. In four-span layouts, use fixed bearings on the abutments and on the center pier; use expansion bearings on the other two piers.

All expansion bearings in skew bridges or in bridges on curves should have the block between girders indicated in Fig. 51.

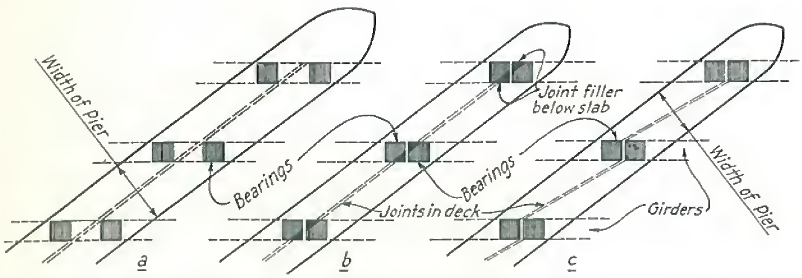


FIG. 52 Three arrangements of girders bearing on piers in a skew bridge. The pier width is often determined by the position of the bearings as indicated in type *a*. The width may be reduced considerably by use of the layouts in types **b** and **c**.

FIGS. 52 and 53

Valuable space may be wasted on piers supporting skew bridges when the bearings are arranged as indicated at *a* in Fig. 52. This arrangement is often adopted for the purpose of obtaining straight deck joints. A narrower pier seat—and a more economical pier and bridge construction—may be obtained by placing the bearings much closer together as indicated at *b* and *c* in Fig. 52. It has been suggested that the deck joint be kept straight by means of a construction as indicated at *b* in Figs. 52 and 53. Some bridge designers use a saw-toothed joint as indicated at *c* in these two illustrations.

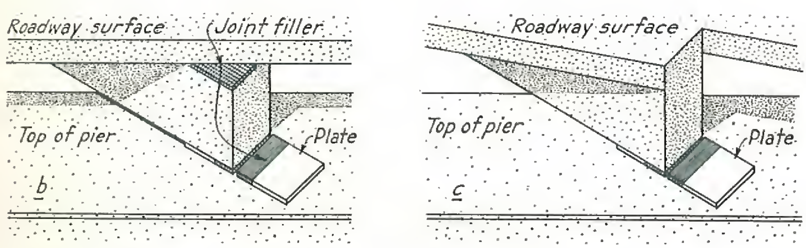


FIG. 53 Details suggested for jointing at piers in skew bridges. Type **b** has a straight deck joint, while the joint in the deck is saw-toothed in type **c**.

When a skew slab as shown in Fig. 46 is loaded and deflects, the deck deformation will tend to raise the acute corner of the deck. Cracks of the type sketched in Fig. 46 may then develop. It is therefore advisable to provide suitable reinforcing bars in the top of the slab at its acute angle and preferably parallel to the long diagonal of the slab.

APPROACH SETTLEMENT

Frequent Maintenance

Maintenance work most frequently performed at bridges soon after completion is the raising of approach slabs that have settled. The cause of the settlement is to be found in the behavior of the backfill.

The backfill behind the abutment is usually of materials such as clay, sand or earth. It is placed in layers but the use of water in the backfilling operation is usually prohibited since the abutments are rarely designed for the added hydraulic pressure. This type of backfill may settle considerably, and it is therefore best to leave a gap in the pavement on the approaches for some time. Such gaps are objectionable, and the approaches are usually paved shortly after the bridge is completed. The result is that the approach slab settles with the fill and cracks.

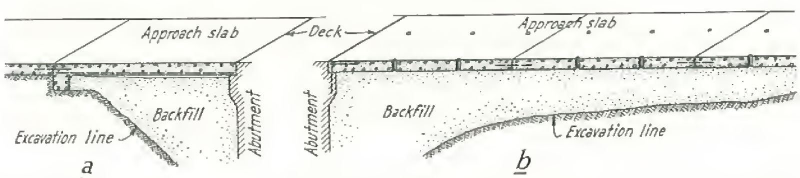


FIG. 54 Two methods used in building approach slabs. The slab in type *a* is self-supporting and will not settle with the backfill. The slab in type *b* does settle with the fill, but provisions may be made for jacking up the slab again.

FIG. 54

Reducing Settlement

The objectionable features accompanying settlement on approaches may be eliminated in some instances. When conditions are favorable, it is advisable that the volume of excavation behind the abutment be kept as small as possible. In other words, the excavation line shown at *a* in Fig. 54 should be made as steep as the type of soil will permit. In addition, it is well to specify for backfill the use of coarse materials, such as stone or gravel. When this type of backfill is too expensive, ordinary earth backfill may be chosen. If so, it is advisable to proportion the approach slab

so that it can safely span from the pavement ledge on the abutment to the undisturbed soil behind the backfill. The approach slab will then remain at its original level when the backfill settles below it.

Typical Approach Slab Practice

Where the top of the undisturbed soil is as indicated at *b* in Fig. 54, the approach slab is usually built in sections. Roughness at transverse joints in the riding surface may be avoided by the use of short dowels extending across all joints, including the joint at the abutment ledge. If the slab should settle with the backfill, it is usually raised to its original grade by means of the mud-pump operation. It may be well to anticipate this operation when the slab is built. Some designers, therefore, specify that holes be left in the slab properly arranged for future use as indicated at *b* in Fig. 54. Such holes may be about 2½ inches in diameter and spaced about 5 feet apart in both directions. They should be filled tightly with mastic to protect the edges and make the holes water-tight.

* * *

Concluding Remarks

A digest of the observations made in the field has been presented with special attention given to those details that can be improved. The details that are being used universally with consistently good results have been omitted because they are so generally understood and require no discussion.

Field observations have led to the conclusion that troublesome effects developed under the most adverse conditions only, although the underlying causes of potential damage often exist. Despite the relative infrequency of troublesome cases, it is advisable to take proper precautions under all similar conditions. Cause, effect and precaution therefore have been given equal attention in the discussion. It is hoped that these studies will stimulate further effort toward perfection of structural details in concrete bridges to keep abreast of the advancement in concrete quality.

PORTLAND CEMENT ASSOCIATION

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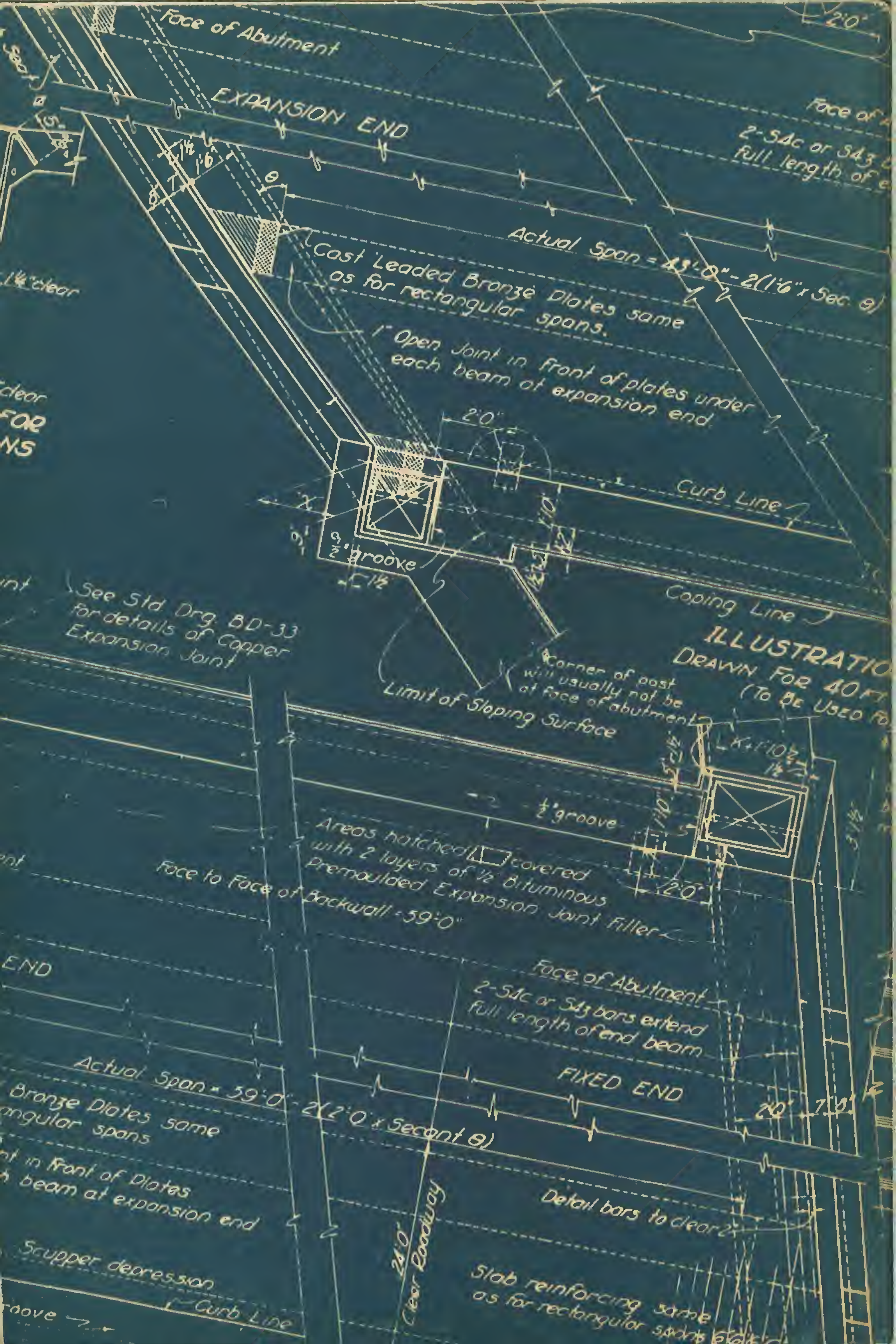
Face of Abutment
EXPANSION END
Actual Span = 43'-0" - 2(1'-6" x Sec. θ)
Cast Leaded Bronze Plates same as for rectangular spans.
1" Open Joint in front of plates under each beam at expansion end
2'-0"
Curb Line
½" groove
Coping Line
ILLUSTRATIO
DRAWN FOR 40 FT
(To Be Used Fo
See Std. Drg. BD-33 for details of Copper Expansion Joint
Corner of post will usually not be at face of abutment
Limit of Sloping Surface
½" groove
Areas hatched covered with 2 layers of ½ Bituminous Premoulded Expansion Joint Filler
Face to Face of Backwall = 59'-0"
2'-0"
Face of Abutment
2-S4c or S43 bars extend full length of end beam
FIXED END
Actual Span = 59'-0" - 2(2'-0" x Secant θ)
Bronze Plates same angular spans
in front of Plates beam at expansion end
Detail bars to clear 2"
24'-0" Clear Roadway
Scupper depression
Slab reinforcing same as for rectangular slabs
Curb Line
END
Face of
2-S4c or S43
full length of e